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COMPLEMENTARY APPROACHES TO THE DIFFUSION OF ICT: EMPIRICAL EVIDENCE ON ITALIAN FIRMS[*]

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Abstract

Using data on the adoption of Information and Communication Technology (ICT) by 1947 Italian firms in 2004 and 2005, this paper provides evidence that is consistent with three largely complementary streams of literature on innovation diffusion. First, as suggested by epidemic models, we highlight the positive impact of early adopters' performance on the rate of diffusion. Second, following probit models, we show how market structure and user characteristics, including their size and competencies, affect ICT adoption. Third and finally, we draw insights from systemic approaches to emphasise the dynamic role played by the public sector and by the technological and institutional context in which user firms are active .

JEL Classification: C34, L11, 033

Key words: Innovation diffusion, Technology adoption, Truncated and Censored Models.

1. Introduction

This paper draws insights from complementary streams of literature to examine the diffusion of Information and Communication Technology (ICT) in the Italian manufacturing and service industries.

The empirical strategy we shall follow is two-fold. First, we shall use Principal Component Analysis (PCA) to derive a composite indicator of firm level adoption of different ICT tools and services. Second we shall run Censored Tobit regressions to identify the relation between the composite indicator and the explanatory variables pointed out by the literature on innovation diffusion. The use of a truncated model is justified by the fact that our dependent variable, i.e. the composite indicator as a synthetic measure of innovation adoption, only takes positive values.

Data are drawn from the "Statistical survey on Information and Communication Technologies within firms" (for the years 2004 and 2005), produced by Italy's National Bureau of Statistics (ISTAT). This source provides detailed information on the usage of ICT within firms in manufacturing and services and it is managed in accordance with European Union regulation in order to obtain representative information of the actual adoption of ICT within firms. The intersection of the two waves of this survey yields performance and ICT data on 1,947 firms that is the basis for the analysis developed in this paper.

Our empirical analysis confirms the positive impact on ICT diffusion of variables typical of probit and epidemic models, like firms' market performance, size and competencies, and a negative impact of sectoral concentration. Moreover, factors generally emphasised by systemic approaches to innovation diffusion also appear to have a significant impact. The latter set of factors includes: firms' access to broadband networks as a proxy of the advancement of telecom infrastructure; the variety of e-Government services supplied by local Authorities, as a proxy of the role played by the Public Administration in experiencing and catalysing innovative activities; whether or not users are themselves ICT equipment manufacturers as an indicator of how active firms are in innovation and adoption of advanced technologies and services.

The paper is organised as follows. Section 2 illustrates some of the most important approaches to innovation diffusion at the sectoral and firm level. Sections 3, 4 and 5 describe the data, the methodology and the outcomes of the empirical analysis. Section 6 summarises the results and draws some public policy implications.

2. Approaches to innovation diffusion

One may identify three main streams of contributions in the existing literature, each allowing for different degrees of heterogeneity of the economic agents involved in innovation diffusion.

2.1 Information asymmetries and risk aversion in the epidemic models

In his seminal contribution, Mansfield [1] highlights that innovation diffusion is affected: a) positively by the profitability of innovation - expectations on high returns from investments will encourage potential users to adopt innovation; b) negatively by the amount of the investment necessary to innovate - reflecting a cautious attitude of users which will be all the more

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constraining the higher the financial burden associated to innovation efforts; c) positively by the ratio between the firms which have already adopted the new technology and the entire potential population of users. A larger number of users will permit a wider flow of information on the characteristics of innovation (epidemic effect). As a consequence, there will be a higher competition among them, a reduction in the uncertainty concerning the novel technology, and a lower reluctance of non-users to acquire it as it gets more and more adopted.

Mansfield also considered other variables which affect innovation adoption, including market growth rates as a predictor of firms' purchasing capacity. However Mansfield was not the first to give attention to the latter variable. In a nutshell, the idea had already been put forth by Schumpeter[1] [2] in his *"The Theory of economic development"* where he pointed out that innovation incentives follow the phases of business cycles, and economic growth will more easily motivate a relevant amount of investment leading to technical change.

From this perspective, the original epidemic contributions appear to be characterised by a rather limited degree of heterogeneity of economic actors involved in innovation diffusion: users are assumed to differ only in terms of the amount of information they have on the available technology – and this varies with sector specific characteristics such as the costs of innovation, the number of adopters and business cycles [3, 1, 4, 5, 6]. They do not differ in terms of their own structural characteristics nor in terms of their strategies.

A number of scholars criticized models of epidemic diffusion because of their allegedly weak theoretical foundations. They find an agreement on a precise point: while epidemic models give a description of the aggregated behavior of the sector in adopting innovations, they do not shed light on the decision of individual firms, thus failing to provide a behavioral explanation of why some firms adopt innovations before others.

Davies [7] argues that it appears quite unrealistic that in a society dominated by mass media, information is assumed to be disseminated thanks to the actual experience of early adopters and to their physical contact with non adopters. Karshenas-Stoneman [8] and Jensen [9] criticize the view that potential adopters are only passive receivers of information, thus disregarding the active role played by some user categories.

Moreover, epidemic models have been criticized for other reasons [10, 11, 12, 13]. First, all firms are assumed as having an equal chance of becoming infected (and hence adopt the new technology). This is an assumption that violates common sense since some firms would naturally seem more prone to adopt innovation than others (for example firms with large cash reserves, higher rates of capital replacement, better managers, etc.). Second, it is not explicitly explained how firms' profit maximizing goals could generate the hypothesized aggregate behavior.

Subsequent contributions, which adopt epidemic-like modelling of innovation, mitigate some hypotheses on homogeneity of users. In these models the idea is put forth that some learning takes place through the interaction and contamination between users and producers, but actors still remain homogeneous in their structure. [14, 15, 16, 17, 18, 19].

2.2 Firm characteristics and market structure in probit models

New approaches on diffusion have developed in response to various criticisms moved to epidemic models. They look more thoroughly into behavioral phenomena such as why firms adopt innovations at different times of their lives (inter-firm theories) of why firms take time to change their production from an old to a new technology (intra-firm theories).

We shall focus here on a wide and variegated set of contributions, often identified as "probit models" [7] or "rank models" [4, 8], wherein diffusion paths are designed considering that potential users of innovation differ from each other in some important characteristics that induce some of them to adopt new technology before others[2]. The basic principles of probit models can be observed in David's studies [20, 21] on the diffusion of the mechanical reaper in the United States before the American Civil War. The idea put forth by this author is that a crucial threshold of technology adoption is reached at different moments in time within industries according to the characteristics of firms and of markets in which they are active. In particular the variables studied by David were: the interest rate, the price of innovation, the size of farms and unit wage levels.

This marks a fundamental departure from the epidemic approach, as more heterogeneity is introduced in these models: the rate and direction of innovation diffusion will differ across and within industries thus reflecting the heterogeneity of firms, markets and institutions.

A number of variables have been identified as affecting diffusion patterns in probit/rank models, including: *Capital vintage, i.e.* firms with older, less productive vintages of capital find it more profitable to adopt innovation than firms with newer capital [22]; *expectations on the returns on the new technology,* which positively affect adoption [23, 24], while *technological expectations* on the rate of innovation will negatively affect adoption; variations in *input prices* across firms and input requirements across technologies, implying that some firms obtain a higher return from the new technology than others; heterogeneous *productivity levels* across firms, implying that some firms obtain a higher net return on adoption than others [25]; differences in firms' exposure or sensitiveness to *regulatory costs*, which may affect the net return on adoption [26]; variations in *switching costs* due to the nature of technologies and/or to competencies of firms, which may change the relative advantage of new technology (Geroski [16], Wosniak [27], McWilliams and Zilberman [28]) and draws attention to the importance of human resources and and competencies in the adoption of innovation [29].

While the variables we have just mentioned do play a key role in shaping innovation diffusion, most of them are hardly observable. Hence most probit-like empirical models have ended up using a few easy to measure structural characteristics of companies and industries, the most commonly emphasized of which is *firm size* [20, 7, 30]: large firms are generally endowed with greater professional abilities which will eventually increase their chances to adopt new technologies. Large sized firms will also have easier access to financial resources, which permits to better cope with problems connected with the introduction of innovation, like the loss of efficiency when the old technology is replaced by the new one. Besides large firms, being endowed with more assets, can live with much higher switching costs as well.

Industrial concentration is also a relevant (and measurable) variable in these models [31, 7]. In a way this is not a characteristic of probit models only: also epidemic approaches do emphasise that a high concentration, being associated with a low number of (potentially adopting) firms, would make adoption a less frequent and hence riskier event, thus reducing the likelihood of "contamination" across users. Probit literature emphasises that the correlation between market concentration and diffusion can be expected to be negative also because a large number of firms operating in the same sector (low concentration) will increase competitive pressure and stimulate them to adopt new, more effective technology.

Another important feature of probit models is the inclusion of variables on the *supply side*, which may play a crucial role in diffusion processes. Producers of new products and processes are themselves responsible for the circulation of information concerning commercial innovation. This will occur directly and on a voluntary basis through their pricing and advertising policies; and indirectly to the extent that they successfully use the technology they produce. Hence their behaviour and performances may have important demonstration effects to the advantage of other users [10].

To sum up, probit/rank models differ from the epidemic ones for their attention to both supply-side and demand-side, and for the role played by a variety variables concerning market structure and firm characteristics (including their size and competencies), thus allowing for a more substantial degree of heterogeneity across and within industries [32, 33, 34].

In spite of the extreme variety of contributions which could be labelled as probit/rank models, a general criticism applying to them is that they largely disregard the complexities of the economic environment, the multiplicity of agents involved in the diffusion process and their resulting interactions. These missing features are at center stage in systemic approaches.

2.3 Systemic approaches: heterogeneity and interaction in the diffusion processes

A third group of contributions extends its attention from the level of firms (as end users or suppliers of technology) to a wider set of interdependent actors involved in the introduction and diffusion of innovation. These works deal with the systemic and interactive nature of this process. By placing more emphasis on interdependence and interactive learning, they account for an even greater degree of heterogeneity of actors than probit models.

Systemic approaches take into consideration, either implicitly or explicitly, a wide range of behaviors, contexts, learning processes, environments, interaction processes and influences of the market and non-market institutions.

Users and producers are distinguished into more specific categories: on the supply side, a crucial distinction is between producers of capital goods, of final goods and of complementary services; on the demand side, the analysis of intermediate users can be separated from that of final users, and the role of public technology procurement can also be isolated. The interaction between actors may influence not only the rate but also the direction of technical change and innovation diffusion [35, 36, 37].

In particular, we shall focus on the interactions between firms (as end users), suppliers (as producers of technologies and providers of telecom services), and public administrations (as technology public procurements). As far as user-producer interactions are concerned, many authors have suggested that the dichotomy between learning by doing and learning by using should be overcome. Among others, Von Hippel [38] identifies a combination of actors (input suppliers, producers of final goods, "active" and "passive" users) from whom innovation can originate and spread. The sources of innovation can then vary according to the combination of actors involved and according to their competencies and cognitive capacities. Lundvall [39] highlights the need for efficient communication channels between users and producers in innovation diffusion. On the one hand, users would benefit from an extensive knowledge of the innovative solutions available as this would help them to select those technologies which meet their needs. On the other hand, producers need quick and continuous access to the experience accumulated by users to improve technology after the introduction and commercialization of innovation. As both users and producers accumulate knowledge on the characteristics of technology and application opportunities through interaction, uncertainty and information asymmetries are reduced, thus partially removing obstacles to innovation diffusion [40].

Besides inter-firm user-producer interactions, a second type of relations, relevant to our research, is the one between firms and the public sector. Scholars have developed a novel approach to the study of these relationships, known as "Public Technology Procurement" (from now on PTP). This approach overcomes the technology push view, which has traditionally theorised a role of the public sector either as the ultimate financer of scientific research or as the end user of technology, with no active role in the development of technology [41]. An important departure from this view relies on the distinction between the role of public administrations as "end users" of technology and public technology procurement as "catalyser, coordinator of technical resources for the benefit of end users", affecting the direction and speed of technical change [42]. This view of the public procurement actors as intermediate technology users seems to better describe the evolution of real world nowadays, as public administrations are more and more involved in the design, early experimentation and development of applications to the benefit of a wide category of end-users, including firms, families and individual citizens. Examples of this changing role of public procurement can be drawn from telecommunications: a transition is taking place from a market structure which has long been characterised by public quasi-monopolist service providers active in national markets, imposing standardised services to passive end-users, towards a situation wherein multiple providers compete for the supply of advanced services to skilled users. Among these providers a key role is played by public administrations which are in a position to test new communication technologies and to develop advanced e-Government services interacting with both ICT suppliers and end-users of advanced technological solutions[3] [43].

While systemic approaches yielded mainly empirical and qualitative contributions, some theoretical models successfully incorporated systemic aspects. This is the case of the models with increasing returns [44, 13] where the heterogeneity of agents, interaction and learning play a fundamental role in the dynamics of adoption and diffusion.

3. Data and methodology

Data are drawn from the "Statistical survey on Information and Communication Technology within firms" carried out by Italy's National Bureau of Statistics, ISTAT (from now on ISTAT-ICT) in 2004 and 2005. The sample design of the ICT surveys is a random stratified sample for firms with 10-249 employees and a census for the firms with 250 employees or more.

The survey is based on a questionnaire, harmonized according to the requirements of the European Union regulation (CE) n. 808/2004 (04/21/2004) for ICT surveys, including information on how the interviewed persons perceive the impact of ICT on firms' performance, employment, e-commerce, business functions and on the typology of ICT adopted.

The overall data-set is composed by firms from the manufacturing and service sectors classified according to the economic activities nomenclature by ATECO/NACE 2002. The intersection between the two sets of ISTAT-ICT data (2004 and 2005) produced a final sample of 1.947 firms[4].

We aggregated firms into 4 sectoral classes according to HT classification (OECD/Eurostat) and KIS classification (Eurostat)[5]. The sample over represents the upper class of large and medium sized firms (100 and more employees) due to the sampling design of the ISTAT surveys: they are census for 100 and more employee firms and a stratified random sample for the smaller ones.

Sector wise the sample is characterised by the high concentration of "Low and medium high – tech manufacturing" (37%) and of "Low - knowledge intensive services" (26%) industries and by the low share of "High and medium high – tech manufacturing" (21%) and "Knowledge intensive services" (16%)[6].

4. Building a composite indicator of ICT adoption

As a first step, we carry out a Principal Components Analysis (from now on PCA) to design a composite indicator summarising a number of different features of ICT diffusion. Then we proceed with a Censored Tobit econometric analysis to examine correlations between the composite indicator and the explanatory variables singled out by the innovation diffusion literature.

A study carried out by the European Commission for the Action Plan eEurope 2005 in January 2003 (EC - JRC) adopted a similar PCA based methodology in a macro-economic context, to derive a synthetic measure of ICT diffusion across different European Countries [45, 46].

Different from the one calculated by EC - JRC, our composite indicator uses micro-data on ICT adoption in the Italian firms, as provided by the Istat data-set described above.

This indicator (from now on CI-ict, Composite Indicator of the ICT adoption) reflects the correlation patterns among six basic indicators of the sample firms' use of ICT observed over period t , with t= 2004, 2005 (Table 1).

The empirical strategy to consider ICT adoption in year 2004 and in 2005 as separate variables reflects the consideration that the decision to first adopt in one year or in the other makes a difference. In fact, ICT adoption was still rather low in the examined period and a lot of firms started to purchase new ICT tools in 2005 only. The low level of correlations between the observed value of each technological variable in 2004 and the value of the same variable in 2005 (see Table 1) confirms that ICT diffusion was at an initial stage at that time.

We first attempted to construct the composite indicators using data on all the technologies recorded in our dataset, but obtained low scores from PCA. We then selected a narrower set of technologies, based on insights from previous literature on ICT diffusion.

[Table 1]

By using the PCA method we are able to economise on the information concerning the variables listed in Table 1 and their inter-relations, hence providing an efficient description of firms' adoption of ICTs[7] [47, 48].

The CI-ict is obtained by summing up each of the elements (weights) reported in the last column of Table 2, which are the result of the linear combination of the first principal component of the correlation matrix calculated for the six variables in each of the two years considered. In technical terms, such elements (or weights) used to compute the CI-ict are defined as the eigenvector associated with the highest eigenvalue of the correlation matrix[8].

[Table 2]

As a result of this procedure, the contribution of the CI-ict to explain the variance of the variables listed in table 1 is 33.46%, while the variance explained by the second component falls to 17.5%.

Tables 3, 4 and 5 show some of the characteristics of the composite indicator and illustrate the average adoption rate of ICT in the sample. In particular, Table 3 highlights that CI-ict, as a continuous and positive variable, presents a minimum value of 0 and a maximum of 3.42890. The number of observations (1921) is lower than the number of sample firms (1947) due to missing values. Table 4 shows that manufacturing sectors (no matter how classified in terms of technological intensity) are characterized by higher CI-ict (and higher average number of ICT tools adopted) than the services sectors. As one could expect, the higher the technological intensity of the examined industries, the greater the value observed for CI-ict. This applies to both manufacturing and services, although the values computed for services are probably underestimated due to the fact that ISTAT-ICT surveys (for 2004 and 2005) do not include some of the most dynamic sectors as the financial and monetary intermediation activities. In accordance with the empirical and theoretical literature, Table 5 shows that the average intensity in adopting ICT is influenced by the size of firms, as revealed by the fact that the value of CI-ict is lower in the case of small and medium enterprises (10 – 99 employees) than in the case of larger firms.

[Tables 3,4,5]

5. Econometric analysis

Econometric exercises were conducted using CI-ict at the firm level as a dependent variable and regressing it on a number of firm and sector level variables which can be used as proxies of the factors highlighted in innovation diffusion literature. See Table 6 for a description of these explanatory variables.

[Table 6]

We used a "censored" Tobit model [49, 50], that is appropriate whenever the dependent variable is quantitative, and the values it takes are bounded by inferior (censored to left) and/or superior thresholds (censored to right). In our case, the model is truncated on the left, and the threshold value is zero, corresponding to lowest possible level of ICT diffusion. Non adopters (107 firms which recorded a zero value for the CI-ict indicator) are slightly less than 10% of the overall sample.

[Table 7]

Table 7 illustrates the results of this econometric exercise and examines the role played by the key variables highlighted in the epidemic, probit and systemic approaches as discussed in section 2 above[18].

The variable ***PERFORMANCE*** is very significant even though the estimated coefficient is rather low. Consistent with the epidemic approaches [1], one might expect a positive impact on CI-ict, as firms facing a phase of economic growth or prosperity are more inclined to invest in new technology adoption.

The negative impact of our market concentration variable, ***M_C***, suggests that firms active in competitive sectors (low concentration), characterized by a large number of firms and by a high elasticity of demand, are more motivated to use innovative technologies including ICT to face competitive pressures [51]. The result obtained thus confirms the hypothesis developed by epidemic and probit approaches [1, 7, 31] according to which competitive pressures associated with a low concentration positively influence the rate of adoption and imitation.

By contrast, firms characterized by a strong market power, are normally expected to have weaker incentives to technology adoption than competitive fringes of new entrants, especially in the case of drastic innovations characterized by high uncertainty [52]. Besides, concentrated industries are more likely to be characterised by firms exhibiting higher organisational complexity and greater x-inefficiency, which might represent a barrier to adoption [30].

The variable ***FIRM_SIZE*** is very relevant and positively influences the CI-ict. This outcome is in accordance with the hypothesis of "critical threshold" put forth by several contributions which would be typically framed in the probit approach [20]. There are several reasons why large firms can be expected to act as "first movers" in the process of ICT adoption [16]. These include: the availability of professional competences needed to handle new technologies; lower financial constraints which permit to undergo higher ICT; access to better credit market conditions.

The variables we used to proxy the absorptive capacity of firms, have the expected positive impact on ICT adoption. ***PC_INTERNET_EMPLOYEES***, as measured by the level of Internet diffusion among employees, is most likely to play a role in creating a dynamic working environment which is conducive to innovation adoption and use. In particular, as PC_INTERNET_EMPLOYEES increases we can expect that the capacity of the firm's employees to develop abilities in the use of ICT services will also increase [53]. In firms with a great number of stand alone PCs (computers not connected to the Internet) employees may face greater difficulties in developing advanced user capabilities. In fact, while the estimated coefficient of PC_INTERNET_EMPLOYEES is positive and significant, one should note that the number of employees using PCs not connected to Internet (PC_EMPLOYEES) does not have a significant impact on CI-ict (and the sign of the coefficient is even negative in this case).

ON_LINE_PURCHASES are positively correlated to CI-ict. This is in accordance with the general expectation that firms with a greater CI-ict are more likely to be able to appreciate the benefits deriving from the use of eCommerce (potential customers) which permits to purchase goods directly on-line. This result is by and large consistent with the concept of "learning by using" [35] as an essential element for the innovation diffusion: the idea is that users will develop greater knowledge about the technology they use, and this will eventually increase the profitability of further adoption of innovation.

In a similar vein, one can observe a positive association between the variable ***SECURITY*** and CI-ict. Firms making a high recourse to information exchanges, to on-line sales and purchases will be most interested in the availability of advanced devices for the security of their own transactions.

The positive impact of the latter explanatory variables (*ON_LINE_PURCHASES* and *SECURITY)* might also be consistent with the widespread belief that on-line transactions have been recently increasing in importance but they do require a greater security of web procedures and controls.

As suggested by several contributions emphasising the systemic nature of innovation diffusion, we also need to assess the role of the more general context in which firms are active. The variable ***INTERNET_C*** can be considered an appropriate proxy of how advanced infrastructures are in terms of broadband connections. The estimated coefficient for this variable, which is positive and significant, shows that CI-ict raises as the band capacity available increases. This result, in accordance with the empirical literature [54, 55], seems to suggest that the continuous evolution of technological applications and ICT services require a better transmission efficiency. Thanks to the availability of adequate communication infrastructures, firms raise the speed of communications and the access to the Internet as well as the use of multimedia interactive services (IC-ict).

We capture the role of the public sector in stimulating ICT adoption through three different dummies concerning eGovernment services provided by local public Administrations (Regions, Provinces, Municipalities). The available data allow to distinguish such services according to their degree of interactivity. E_GOV_INFO accounts for the availability of aggregated services through which firms and citizens can merely aim at "obtaining information", with limited or no interactive content. E_GOV_FORMS identifies aggregated services allowing the "downloading of forms" while E_GOV_TRANSACTIONS imply the possibility of "activating - concluding a proceeding and transactions web services". It appears that the impact of E_GOV variables is always positive but also increases in both levels and significance with the degree of interactivity[19].

The fact that a wider ICT adoption is influenced by the availability (and quality) of e-Government services is broadly consistent with some of the hypotheses put forth by systemic approaches [37, 43, 56], according to which public procurement activities may play a specific role in catalysing innovation. The role of Public Technology Procurement in stimulating ICT adoption by firms appears to have increased with the proliferation of local administration bodies which are involved in the testing and promotion of technology within their local territory [57].

Our results can be made roughly consistent with the outcomes of the descriptive analysis carried out by Eurostat [58] which highlight that the diffusion of eGovernment services aimed to provide mere information is highest in EU15 countries. While it may be true that the eGovernment services with the lowest interactive content are the most diffused – although things might have changed over the past few years – it remains that it is the most interactive services that appear to better stimulate ICT adoption among firms.

An important control introduced in the analysis concerns the sectoral composition of firms belonging to the Istat sample. Firms belonging to ICT sectors (***ICT_SUPPLY***) are most likely to use ICT as well. In fact, following seminal insights by Rosenberg [35], one can suggest that ICT firms have a strong incentive to adopt and experience the use of the technology they produce. In fact, through usage experience, producers of new technology increase their knowledge of the technology itself and improve the quality of the products they sell. Besides ICT suppliers, through their offerings of ever new and improved technologies and services, may also stimulate users to invest in competence accumulation and hence affect the pace of technology adoption [59].

6. Conclusions and public policy implications

This paper considers innovation diffusion processes, and tests the determinants of ICT adoption using data from a sample of 1.947 Italian firms in 2004 and 2005. We review some leading approaches to innovation diffusion to identify the key variables to be considered in the empirical analysis.

We find a positive impact on ICT diffusion of variables typical of probit and epidemic models, like market performance, the degree of competition, firm size and competencies. Moreover, factors strictly related to systemic approaches to innovation diffusion also appear to have a significant impact: access to broadband networks as a proxy of the advancement of telecom infrastructure; the variety of e-Government services supplied by local administrations, as a proxy of the role played by the Public sector in experiencing and catalysing innovative activities; the supply of ICT equipment as a vehicle of innovation and as a spur to adopting and experimenting advanced services.

The analysis carried out in this paper has several policy implications. First of all, it appears that policies aimed at promoting the ICT adoption and diffusion should significantly differ according to the sectors in which users are active; and to the size of potential users. This turns out clearly at all levels of the empirical analysis carried out in the paper. On the one hand, we obtain a composite indicator (CI-ict) of the overall level of ICT adoption which exhibits a higher average intensity for manufacturing than for service industries; and for high tech sectors than for low tech ones. Moreover the indicator is significantly higher for medium-large firms with 100 and more employees than for the medium-small ones with 10-99 employees. On the other hand, the econometric analysis clearly confirms the positive and significant role of firm size, and that ICT adoption is positively associated to the technological intensity of sectors.

Econometric analysis also highlights a strong positive link between the use of broadband connections and ICT adoption. This seems to suggest that policy makers should give more attention to the "digital divide" phenomenon. Italy has been moving faster and faster in this direction by implementing new technologies and guaranteeing a widespread diffusion of broadband in the territory [60]. However the spontaneous dynamics of the local access market does not guarantee adequate private funds towards disadvantaged zones. As a consequence, differentiated public policies are needed guarantee a non discriminatory access to advanced services to citizens, firms and local administrations in all areas of the country.

Moreover, our study confirms the negative impact of market concentration, which appears to act as an important barrier to ICT adoption. Of course, this provides a rationale for measures aimed at weakening monopoly conditions, especially in telecommunications and energy sectors, and more in general to guarantee fair competition on different markets to create favourable conditions to technology diffusion. However we cannot ignore that small size of firms also constitutes a significant obstacle to ICT diffusion. For this reason it appears to be necessary to promote firms' growth and their technological competences; but also to stimulate, especially in Italy, the collaboration between firms and institutions supporting small sized companies in order to develop technological solutions suitable for adoption in fragmented industries.

We also find that the presence of dynamic ICT producers positively influences the adoption of ICTs. This makes a strong case for interventions aiming to strengthen and sustain these business sectors [61] which represent an important vehicle to innovation and are important users themselves, and significantly stimulate the adoption of new technology. More in general, public interventions oriented to stimulate ICT demand and supply should provide R&D incentives but also foster co-invention and co-testing of new technologies [62].

Econometric analysis shows that the availability of tools enabling ICT use (like PCs connected to the Internet) favors a greater adoption within firms. We find a poorly significant correlation, which could suggest the difficulty in measuring the impact of organizational and cultural factors which are at the basis of ICT use. These factors include improvements in organizational and managerial practices by means of different tools and services (e-working, e-learning, remote data processing and communication through portable computers with wireless connection to the Internet) supported by specific training.

Finally, our study highlights the role of public administration, especially through the development of e-Government services, in stimulating ICT adoption within firms. Policies supporting the diffusion of e-Government are being carried out at both the central level [63, 64], using public funds awarded by UMTS licenses; and at the local level. However e-Government projects which involve various local administrations in Italy (Regions, Provinces, Municipalities) are about to get implemented nowadays, so the benefits towards citizens and firms will be visible only in the future.

To conclude, we would like to draw attention to one final aspect. Many of the topics which we have touched upon call for a careful consideration of different streams of literature which were not taken into account in this paper. These include contributions on the spatial diffusion of innovation which have been largely disregarded by industrial organisation literature and have been mostly developed by urban and regional economists and economic geographers [65, 66, 67, 68, 69]. The exploitation of complementarities between approaches stemming from different schools of thought and focusing on different units of analysis (firms, sectors and regions) opens up new important research horizons for the future.

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Appendix

[Table 8]

Footnotes

1. Though Schumpeter is considered the forerunner of the studies on diffusion, it is essential to point out how his vision of the phenomenon significantly differs from the one which eventually emerged in the epidemic approaches. In fact he identifies diffusion with mere imitation which originates every time the introduction of new products and/or processes generates better profits for the innovator and encourages other competing, more risk averse firms to emulate the pioneer.
2. The terms used to identify these approaches refer to the fact that, due to the heterogeneity of users, diffusion patterns can be modelled by means of probit-like distributions, and the intensity of adoption varies according to how firms rank along a continuum of characteristics. Other research streams are somewhat related to the ones we have just mentioned, but will not be dealt with here, including game theoretic models on the one hand, and evolutionary disequilibrium models on the other hand. The former set of models theorise technology adoption as equilibrium choices stemming from strategic interaction; whereas the latter stress the role of competence accumulation and market selection as key factors shaping diffusion patterns over time. See Stoneman and Battisti [70] for a review.
3. Reasons underlying this transition include: a) the diffusion of micro-electronics and complementary technologies (software, fibre optics, opto-electronics, satellite technology) which have increased the span of innovation opportunities and challenges for service suppliers; b) institutional changes which have led to a break-up of monopoly conditions in telecommunications industries across most advanced economies; c) increasing privatisation of communication service provision in EU countries which has opened up new market opportunities; d) a demand for more efficient services by public administrations which can be met using more advanced information processing and tranfer.
4. The intersection between the two sets of data referring to 2004 and 2005 respectively was obtained by identifying firms with the same company code and by the same sector codes in both waves. At any rate, the time span for which data are available is not sufficient to make it possible to use panel data techniques.
5. For further details on these two classifications please see Appendix.
6. The medium and large firms' greater weight in the sample is due to the ISTAT-ICT sampling methodology for the years 2004 and 2005. In fact these surveys are based on samples regarding firms with 10-249 employees and on a census of firms with 250 employees or more.
7. PCA is based on a transformation of the matrix of correlations calculated across all the observed variables, and obtains a set of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.
8. The adoption of the correlation matrix as a basis for the calculation of eigenvalues is functional also to put emphasis on the exploitation and persistence of technologies: technologies that are adopted both in 2004 and in 2005 record higher correlations than technologies that are used only in 2005.
9. For all the explanatory variables and for the composite indicator we refer to year 2004 and 2005 like in the Istat sample.
10. Sales include revenues from manufacturing as well as service activities of firms.
11. Market concentration, a typical variable for epidemic models, is also relevant for probit models.
12. Sectors' classification is referred to HT (OECD/Eurostat) and KIS (Eurostat) classifications. For further details please see Appendix.
13. e-Government services aggregation described in this paper is in accordance with Eurostat classification methodology, European Commission (eEurope 2005) and the Italian Ministry for Innovation and Technology.
14. The definition of "ICT sector" used in this paper refers to OECD [71] "Measuring the Information Economy". This definition is based on the international classification ISIC (rev.3) in accordance to the European classification NACE (rev.1) and the Italian one ATECO91. The ICT sectors as classified in the ISTAT sample and included in the OECD classification are: DL 30, DL 3130, DL 32, DL 3320, DL 3330, G 5143, G 5164, G 5165, I 6420, K 7133, K 72.
15. Except for firms active in ICT manufacturing sectors included in the Istat sample.
16. Except for firms active in ICT service sectors included in the Istat sample.
17. The dependent variable is $y = 0$ if $CI\text{-}ict \leq 0$ and $y = CI\text{-}ict$ if $CI\text{-}ict > 0$.
18. Other authors have adopted a similar methodology methodology. Among them Lucchetti and Sterlacchini [72] used principal components analysis and tobit regressions to examine ICT diffusion in Italy, although their dataset was smaller and less rich than the one used in this paper.
19. Except the variable E_GOV_FORMS which is not significant. This result can reflect a low level of services implementation within the variable E_GOV_FORMS by Public Administrations.
20. The column points out the sample sectors not included in the Eurostat/OECD classifications.

Tables

Table 1
Selection of the CI-ict basic indicators

Table 2
CI-ict Weights Correlation Matrix

	Purchases_04	Prod_Log_04	Customers_04	Dig_Serv_04	Adv_Serv_04	Web_Site_04	Purchases_05	Prod_Log_05	Customers_05	Dig_Serv_05	Adv_Serv_05	Web_Site_05	Weights
Purchases_04	1.000												0.300
Prod_Log_04	0.557	1.000											0.317
Customers_04	0.509	0.572	1.000										0.297
Dig_Serv_04	0.167	0.236	0.169	1.000									0.202
Adv_Serv_04	0.156	0.179	0.160	0.196	1.000								0.243
Web_Site_04	0.158	0.175	0.199	0.177	0.502	1.000							0.305
Purchases_05	0.368	0.351	0.304	0.167	0.123	0.154	1.000						0.305
Prod_Log_05	0.392	0.439	0.319	0.202	0.128	0.156	0.655	1.000					0.326
Customers_05	0.294	0.294	0.312	0.136	0.130	0.130	0.435	0.481	1.000				0.268
Dig_Serv_05	0.163	0.173	0.161	0.319	0.178	0.206	0.209	0.255	0.151	1.000			0.217
Adv_Serv_05	0.154	0.161	0.172	0.172	0.371	0.621	0.185	0.192	0.170	0.2151	1.000		0.318
Web_Site_05	0.158	0.172	0.176	0.162	0.358	0.690	0.187	0.200	0.180	0.232	0.869	1.000	0.326

Table 3
Descriptive statistics on CI-ict

Number of Observations	Number of Variables	Average
1921	12	1.9724
Standard Deviation	**Minimum**	**Maximum**
0.9362	0	3.4289

Table 4
Sectoral patterns of ICT adoption

Sectoral Class	Number of sample firms	Average value of CI-ict	Average number of ICT adopted
High and medium high – tech manufacturing	407	2.35	8.10
Low and medium high – tech manufacturing	730	2.07	7.05
Knowledge Intensive Services	310	1.51	5.26
Low-Knowledge Intensive Services	500	1.82	6.26
Total	1947	1.93	6.67

Variable number and name	Variable description
1) Purchases_t	Use of ICT tools for the management of input purchases at time *t* (=1 if firm *i* uses such tools, =0 otherwise)
2) Prod_Log_t	Use of ICT tools for the management of production and logistics at time *t* (=1 if firm *i* uses such tools, =0 otherwise)
3) Customers_t	Use of ICT tools for the management of customer care at time *t* (=1 if firm *i* uses such tools, =0 otherwise)
4) Dig_Services_t	Use of Internet services at time *t* (=1 if firm *i* uses such tools, =0 otherwise)
5) Adv_Services_t	Use of web devices to commercialise and promote goods/services at time *t* (=1 if firm *i* uses such tools, =0 otherwise)
6) Web_Site_t	Use of proprietary web-site at time *t* (=1 if firm *i* uses such tools, =0 otherwise)

Table 5
ICT adoption by firm size

Occupational Class	Number of sample firms	Average value of CI-ict	Average number of ICT adopted
10 - 99 employees	642	1.49	5.06
100 and more employees	1305	2.20	7.63
Total	1947	1.85	6.35

Table 6
Explanatory variables

Variable number and name	Variable description[9]
Typical variables in epidemic models	
1) PERFORMANCE	Performance: average sales per employee in firm *i*[10]
2) M_C[11]	Market concentration: Herfindal index calculated on the number of firms and of employees in sector *j*[12]
Typical variables in probit models	
3) FIRM_SIZE	1 if firm *i* has 100 and more employees; 0 otherwise
ABSORPTIVE_CAPACITY	Absorptive capacity for the ICT use within the firm's employees
4) PC_EMPLOYEES	Average number of employees using a Personal Computer connected and not connected through the internet in firm *i*
5) PC_INTERNET_EMPLOYEES	Average number of employees using a Personal Computer connected through the internet in firm *i*
6) ON_LINE_PURCHASES	1 if firm *i* uses online purchase services; 0 otherwise
Typical variables in systemic approaches	
7) INTERNET_C	1 if firm *i* has access to broad band connecting services; 0 otherwise
E_GOVERNMENT	eGovernment services adopted by firms. Three dummies according to the level of interactivity of services offered by the Public Administration[13]
8) E_GOV_INFO	1 if firm *i* adopts services like "obtaining information" ; 0 otherwise
9) E_GOV_FORMS	1 if firm *i* adopts services like "downloading forms" ; 0 otherwise
10) E_GOV_TRANSACTIONS	1 if firm *i* adopts services like "returning filled in forms and transactions web services" ; 0 otherwise
11) ICT_SUPPLY	1 if firm *i* belongs to the ICT sectors[14]; 0 otherwise

Other controls	
	Sectors fixed effects. Industrial sectors are classified according to HT (OECD/Eurostat) and KIS (Eurostat) classifications
12) HT[15]	1 if firm *i* belongs to the sectoral class "High and medium high – tech manufacturing" ; 0 otherwise
13) KIS[16]	1 if firm *i* firms belongs to the sectoral class "Knowledge Intensive Services (total)" ; 0 otherwise
14) SECURITY	Information tools guaranteeing the security of the corporate work procedure: number of applications for security adopted by firm *i* (1 to 7 range)

Table 7
Tobit Regression: factors influencing CI-ict adoption

	CI-ict censore to 0[17]		
explanatory variable	Parameter estimated	Standard error	P - value
1) PERFORMANCE	.0367***	.0137	.0073
2) M_C	-2.2008***	.3269	.0001
3) FIRM_SIZE	.2420***	.0276	.0001
4) PC_EMPLOYEES	-.0111	.0100	.3066
5) PC_INTERNET_EMPLOYEES	.0888*	.0458	.0526
6) ON_LINE_PURCHASES	.1974***	.0241	.0001
7) INTERNET_C	.1341***	.0357	.0002
8) E_GOV_INFO	.0816*	.0439	.0632
9) E_GOV_FORMS	.0788	.0503	.1177
10) E_GOV_TRANSACTIONS	.1450***	.0292	.0001
11) ICT_SUPPLY	.2286***	.0570	.0001
12) HT	.0643**	.0320	.0445
13) KIS	.1068	.0764	.1678
14) SECURITY	.0886***	.0094	.0001
15) INTERCEPT	-.3146***	.0555	.0001
σ	.4964	.0082	
Log Likelihood	-1322.1644		
Name of Distribution	Log-normal		
Number of Observations	1840		
Non censored Values	1840		
Left Censored Values	0		
Zero Response	107		
"*" Little significant values (0.05<p<0.1); "**" Rather significant values (0.01<p<0.05); "***" Very significant values (p<0.01)			

Table 8
Manufacturing and services according to OECD and Eurostat Classification

Manufacturing according to HT (OECD/Eurostat Classification)	Equivalent Nace 2-digit codes	Comparison with sectors ISTAT-ICT (2004-2005)[20]
High – tech manufacturing	30,32 and 33	
Medium high – tech manufacturing	24,29,31,34,35	
High and medium high – tech manufacturing	24,29 to 35	* (all)
Medium low – tech manufacturing	23,25 to 28	
Low – tech manufacturing	15 to 22,37,36	
Low and medium high – tech manufacturing	23,25 to 28,15 to 22,36,37	* (all)
Services according to KIS (Eurostat Classification)		
Knowledge Intensive Services (total)	61,62,64 to 67,70 to 74,80,85,92	* (Except: 65-66-67-80-85-92)
Knowledge Intensive high – tech Services	64,72,73	
Knowledge Intensive market services (excluding high – tech and financial services)	61,62,70,71,74	
Knowledge Intensive financial services	65,66,67	
Other Knowledge Intensive Services	80,85,92	
Low-Knowledge Intensive Services (total)	50 to 52,55,60,63,75,90,91,93,99	* (Except: 75-90-91-93-99)
Low-Knowledge Intensive market Services	50 to 52,55,60,63	
Other low-Knowledge Intensive Services	75,90,91,93,95,99	

Biography of the authors

Davide Arduini since 2008, is contract Professor of International Industrial Economics at University of Urbino and collaborates with the Interregional Center for Information, Geographic and Statistical Systems (CISIS). He holds a PhD in Economics (2006) and Master of Science in Economics (2003) from Polytechnic University of Marche. In recent years he has been involved in several collaborations with the following institutions: the National Centre for Information technology in the Public Administration – CNIPA (2005-2008); the Formez - National Centre of training and study (2002-2005). In the period 2005-2008 he was the responsible of CNIPA for the ICT survey on local public Authorities (Regions, Provinces, Municipalities) and contributed to the ISTAT methodology - Italy's National Bureau of Statistics. His research focus on Economics of technical change and technology policy, innovation diffusion, patterns of innovation and industrial dynamics in the ICT sector and in the eGovernment sector, market structure and industrial dynamics, regional economics.

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